Application of Surge Capacitors to Mitigate High Transient Recovery Voltage

Gopal Gajjar, GR Patel, Amitabh Khandkar

ABB Ltd. Maneja, Vadodara, India

ABSTRACT

Situations like interruption of Short Line Fault (SLF) current, transformer terminal fault current and series reactor terminal fault current sometimes imposes severe transient recovery voltage requirements on the circuit breakers than those specified by IEC62271 – 100. The exact values and form of the Transient Recovery Voltage (TRV) and Initial Transient Recovery Voltage (ITRV) depend on the type of fault, the line surge impedance, reactance and capacitance of the transformer/reactors etc. The value of the TRV can be beyond the available circuit breaker capabilities hence, circuit breaker application check have to be made before breaker selection in a switch yard. This high transient recovery voltage can be reduced to an acceptable level through application of the shunt capacitors in the switchyard. These 'surge' capacitors have values in order of few nanoFarads, thus they are different from the reactive power compensation capacitors. The paper brings out selection criteria for these surge capacitors through case studies, considering the breaker capabilities and installation space constraints.

1 INTRODUCTION

Modern SF_6 circuit breakers are almost universally used breakers for 66 kV and above system voltages. They are also deployed in significant numbers at many indoor and out door medium voltage applications.

It is well known that SF_6 breakers are suitable for most of the applications but are some times sensitive to situations like short line fault or transformer limited faults. The intent of this paper is to bring out the situation that can cause worry and its remedy.

First of all the shortline fault and the transformer limited faults are described and compared with the terminal fault. The reasons for high TRV in these cases are described in the following section. The relation of TRV produced by SLF and ITRV is explained.

2 SHORT LINE FAULT

High voltage circuit breakers are rated based on the maximum terminal fault current. This is highest level of fault current that will occur if a fault location is immediately adjacent to the circuit breaker opposite the source side. In addition to providing fault current interruption up to this rating, the circuit breaker must be capable of withstanding the TRV appearing across the circuit breaker after interruption. In case of terminal fault, the fault side component of the TRV is zero, and the resulting TRV is attributed completely to the source side component. This TRV is either 1-cosine or exponential-cosine voltage wave, with a peak typically occurring after several 100s of microseconds [1]. The typical TRV waveform as applied by IEEE Std. C37.06 is shown in Fig. 1.

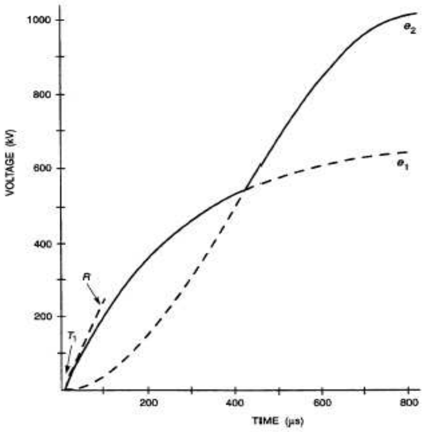

Fig. 1

The terminal fault TRV is characterized by a small time delay of about 2µs to 4 µs followed by a slowly rising TRV. The peak voltage reaches a high value of 1.88 times the rated line-to-line voltage.

However, when the fault is located some distance from the breaker (1 to 3 kilometers), see Fig. 2, a significant voltage oscillation occurs on the line side of the breaker after interruption.

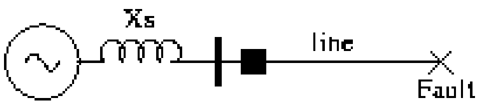

Fig. 2

This voltage arises from the trapped energy on the line section between the breaker and the fault location. Because cables and overhead lines have distributed constants, the line side voltage oscillates in the form of a traveling wave with positive and negative reflections at the open breaker and at the fault, respectively. The line side component of the recovery voltage has a saw-toothed shape and a high rate of rise. As seen earlier, the source recovery voltage rises much more slowly and only the line side triangular recovery voltage is important during the early portion of the TRV. The time to first peak depends on the length of line between the breaker and the fault. It is equal to the time taken by the traveling wave (with velocity nearly equal to that of light, in case of overhead transmission line) to cover the distance twice. The peak voltage of the first peak is slightly lower than twice the voltage that appeared at the breaker terminal at the time of the current zero. There is a very short time delay of 0.2 µs to 0.5 µs prior to the rise of TRV. The typical TRV waveform observed is shown in Fig. 3.

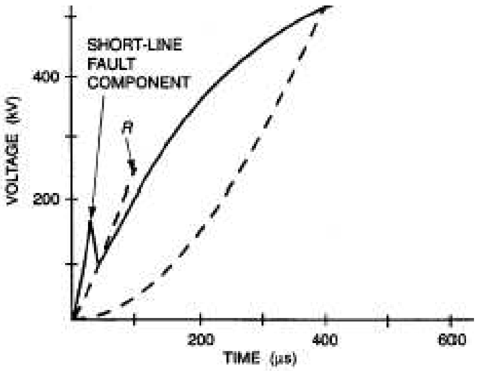

Fig. 3

Depending on the interrupted current and the distance of the short circuit point on the line, the Rate of Rise of Recovery Voltage (RRRV) of line side oscillation is between 3 kV/µs to as much as 10 kV/µs. As the fault location moves away from the breaker, the line impedance increase which reduces the fault current to a lower percentage of the terminal fault current but produce higher voltage peak in the line side TRV. Though, the time to first peak increases as the wave have to travell longer before it gets reflected.

As the RRRV increases, the probability of successful interruption decreases. The most severe short line fault condition is extremely rare in service. The most onerous breaker stresses only occur when the highest fault current levels are available (40 kA for a 40 kA breaker), when the line surge impedance is high (450 Ohms), and faults occur in the most critical locations. This high RRRV can be avoided by using surge capacitors at the appropriate locations. This will be discussed in detail in the later sections.

3 TRANSFORMER AND REACTOR LIMITED FAULTS

The TRV appearing in case of a fault current that is largely determined by the source side transformer or fault current limiting reactors are also called oscillatory TRV. Generally in case of the terminal fault current, the source side TRV is determined by the electrical connection on it, that include all the fault feeding elements and the transmission lines connected to the source side bus. As noted in [1], when ever the source side bus has even a few tens of kilometer length of overhead line connected then the source side TRV is having exponential characteristics as seen in initial part of the TRV waveform of Fig. 1.

The typical circuit configuration normally observed in case of many circuit breaker operations is shown in Fig. 4.

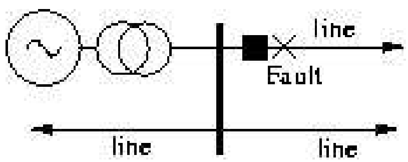

Fig. 4

In these cases, the fault current may be fed from the local source as well as from the remote source through the healthy lines connected to the bus.

The case of transformer limited fault is generally observed in rural radial feeders, where there may be a single line emanating from a transformer. The normal circuit configuration as seen in Fig. 4 can also turn in to transformer limited fault if the other lines breaker are already open or they open earlier than the faulty line breaker because of poor relay coordination.

The circuit configuration of transformer limited fault and series reactor limited fault is as shown in Fig. 5 and Fig. 6(a) and Fig. 6(b). As shown in case of the series reactor, it is immaterial weather the breaker is positioned on load side or line side.

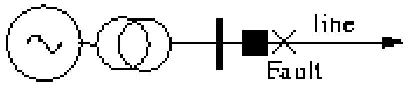

Fig. 5

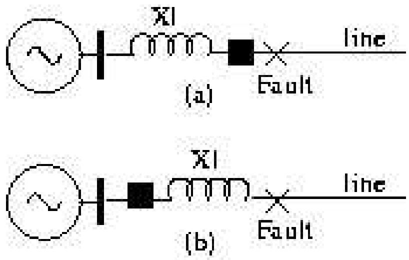

Fig. 6

The fault current in case of transformer limited fault is generally less than 25 % of the rated breaking current of the breaker, and in case of reactor limited fault it may be between 80 % to 100 % of the rated breaking current. The TRV is determined by the inductance and capacitance of the transformer and the capacitance between the transformer and the circuit breaker. It is a high frequency transient that exceeds the capability curve of the circuit breaker defined by the standards. This TRV is oscillatory in nature as against the exponential nature of the TRV of general terminal fault. The reactor limited faults are also of similar nature as the transformer limited fault. Wavetraps used in transmission line communication system may also add a high frequency component to the TRV although of a lesser magnitude than a transformer or a current limiting reactor.

The TRV observed in this case is as shown in Fig. 7. As seen here its frequency is in terms of 10 kHz. to 50 kHz., but the peak magnitude of the voltage reached is less than the peak TRV capability of the breaker.

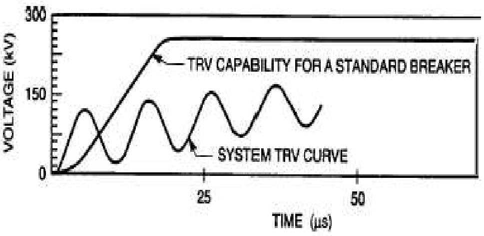

Fig. 7

Generally, this type of oscillatory TRV is called Initial Transient Recovery Voltage (ITRV). ITRV has negligible time delay and its RRRV is high. It is present in all systems but its magnitude is small, and it damps to very small value quickly. But in case of transformer and reactor limited fault its value is high and damping is slow.

Standards treat ITRV requirements same as that of SLF requirements. The type test proving SLF requirements like L90 and L60 also proves the ITRV capability of the breaker.

4 REMEDY

As seen in previous sections, the conditions like short line fault and transformer limited faults can result into generation of such TRV that is out side the tested circuit breaker capability. Although the situations are quite rare, whenever such situations arise the user has three alternatives for achieving reliable performance of the breaker.

1. Reconfigure the system, to avoid the transformer and reactor fed faults.
2. Specify a breaker with higher interrupting rating and higher voltage rating.
3. Apply surge capacitors at terminal of circuit breaker to reduce RRRV.

The first two options are sometimes not feasible or their cost may be prohibitive. The third option of adding surge capacitors is quite effective and economical.

There are number of options where to connect the surge capacitors. Generally surge capacitors can be connected between, (a) ground and the source side bus, or (b) it can be connected across the breaker contacts, or (c) between the ground and line as seen in Fig. 8.

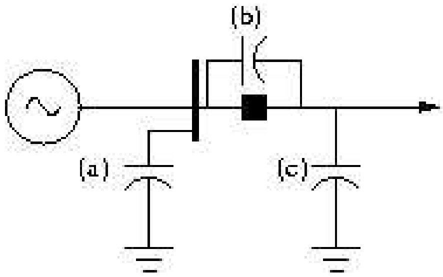

Fig. 8

Each method can be applied individually or in combination depending on the system requirements. The value of surge capacitors required has to be determined through calculations or through electromagnetic transient simulations. Generally, the complicacy of the system and the number of configurations to be considers dictates that it can be done only through simulations. Software tools like PSCAD/EMTDC or ATP/EMTP are used for such purpose.

It is advisable to identify the vuneralable system condition apriory and perform circuit breaker application check before specifying the circuit breaker for a particular job. If it is anticipated that the system TRV may go beyond the breaker capability then use of TRV controlling surge capacitors should be considered.

We present two actual case studies where the application of surge capacitors has helped in reducing the system RRRV and improved the circuit breaker performance under adverse condition.

4.1 Case 1

Here a 66 kV out door, SF_6 circuit breaker connected to rural feeder is considered. The system configuration is such that the breaker had to withstand the transformer limited fault condition on source side as well as the SLF condition on the line side.

PSCAD/EMTDC simulation was performed to check the breaker suitability and check any requirement for modification in the system. The fault current for the three phase ungrounded terminal fault was about 10 kA. When a short line fault is considered at a distance of 3 km. the fault current reduces to 4.6 kA rms, symmetrical. The system TRV produced in this case is shown in Fig. 9. Here it can be seen that the TRV peak voltage is about 65 kV, and it is reached at 30 µs. The RRRV is 2.17 kV/µs. Moreover, the Time Delay (td) is of 3 µs. The value of td is small compared to that specified in the standard [2]. There is a possibility of breaker failure because of this. As the ITRV experienced by the breaker is higher than that for which it was designed.

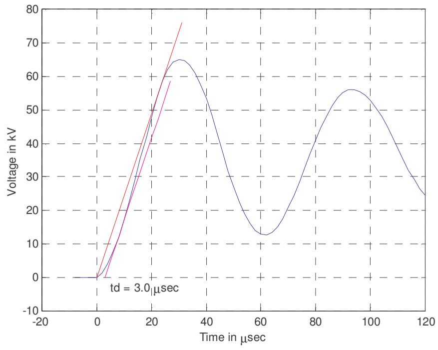

Fig. 9

This TRV is a combination for SLF and transformer limited fault. The breaker is capable of successfully clearing the fault if the TRV produced due to SLF only occurs and the sour side TRV is of exponential kind, or if there is a terminal fault and only the oscillatory TRV due transformer fed fault is there, but the combination of these two TRVs produce sever condition for the breaker.

The solution in this case is to provide a surge capacitance on the source side of the breaker, between the breaker and ground as well as on the line side between the breaker and the ground. The value of both the side capacitance selected as 26400 pF. The TRV observed in this case is shown in Fig. 10

In this case, the time delay td is increased to 6.49 µs. The time to first peak is 58 µs. and RRRV is 1.1 kV/µs. These values are within breaker capability as per the standard requirements. Thus, the capacitor application can improve the breaker operation reliability. A rare situation that produces a high TRV is mitigated through application of appropriate surge capacitors.

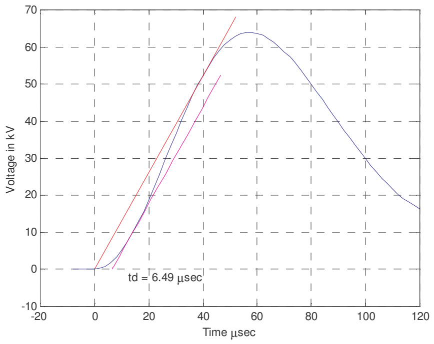

Fig. 10

4.2 Case 2

This case pertains to an 11 kV, indoor SF_6 breaker, operating in conjunction with a current limiting reactor. Here 0.28 Ohms series reactors are used to limit the fault current in outgoing feeders to a value of 20 kA. The system is working satisfactorily since last 20 years with Air Blast Circuit Breaker (ABCB). Now it is required to retrofit the ABCB breakers with SF_6 breakers. The SF_6 breaker application check is required before retrofitting. The TRV with ABCB and SF_6 are different because, the ABCB breaker have parallel resistor connected across the breaker contacts, to limit the TRV due to current chopping. This resistor also helps in the case with reactor fed fault. The SF_6 breaker does not have any such resistor, hence, its TRV is high and goes beyond the breaker capability.

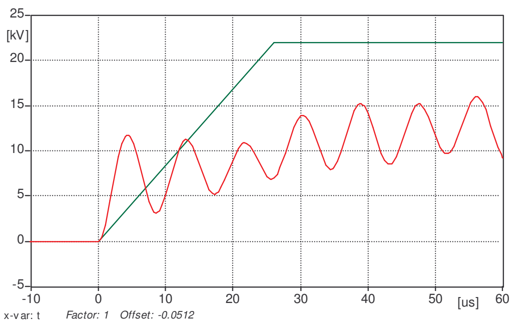

Fig. 11

The system was simulated in ATP/EMTP and the result of condition with SF_6 breaker is shown in Fig. 11. Here it can be seen that the peak TRV is 11.7 kV, and time to peak is 4.25 µs. The RRRV is 3.13 kV/µs. The system TRV is compared to the standard TRV of test T60, as the fault current is below the 60% of rated breaking current (40 kA).

In this case it is calculated that a capacitance of 100 nF to ground, connected in between breaker and the series reactor would provide enough delay in TRV, to enable the satisfactory breaker performance. This is seen in following Fig. 12.

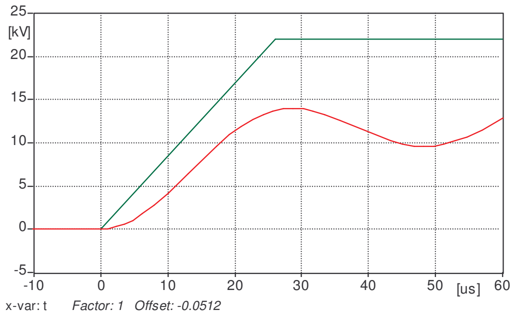

Fig. 12

5 CONCLUSION

As discussed in the paper the system conditions like short line fault and transformer fed faults, which may impose severe TRV requirements in circuit breakers, which are not covered by IEC62271-100 specifications. It is shown that it is possible to reduce RRRV to an acceptable level by proper application of surge capacitors. Electromagnetic transient studies are recommended to perform breaker application check, if any such situations are anticipated.

6 REFERENCES

1. IEEE Std. C37.011-1994, "IEEE Application Guide on Transient Recovery

Voltage for AC High Voltage Circuit Breakers Rated on Symmetrical Current Basis”.
2. IEC 62271-100, “High Voltage Switch-gear and Control gear – Part 100 High Voltage Alternating Current Circuit Breakers”.